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THE INTRA-AXIAL COURSE OF THE AUDITORY TRACT.

By E. C. SPITZKA, M. D.

Step by step investigators are unraveling the fiber-labyrinth of the brain. Where the microtome fails us, there clinical observation of the effect of focal lesions and of secondary degenerations supplements our knowledge; and, where both lines of research leave us in the dark, the atrophy method introduced by the lamented von Gudden takes up the thread. The exactitude of this method is such that a single result obtained by its use outweighs in reliability the observations made by all the other methods albeit cumulative. The only one which approaches it may be regarded as a pathological imitation of the results of the atrophy method: the study of the secondary degenerations.

There is another means of determining the function of nerve-centers and nerve-tracts. It is the comparison of their relative development in animals having exalted or rudimentary special functions. In a crude way this method was followed by Burdach, Gratiolet, Solly, and the older writers. It was somewhat elaborated by Meynert in connection with his projection theory. But only a minimal part of his published results in this field has been sustained by more recent and thorough investigators. It was Gudden again who, with his distinguished pupil, Forel, discovered a number of interesting and valuable facts by the study of animals possessing rudimentary eyes, such as the mole and the blind

rat of Palestine. There are other animals which constitute, as it were, natural atrophy or hypertrophy experiments.

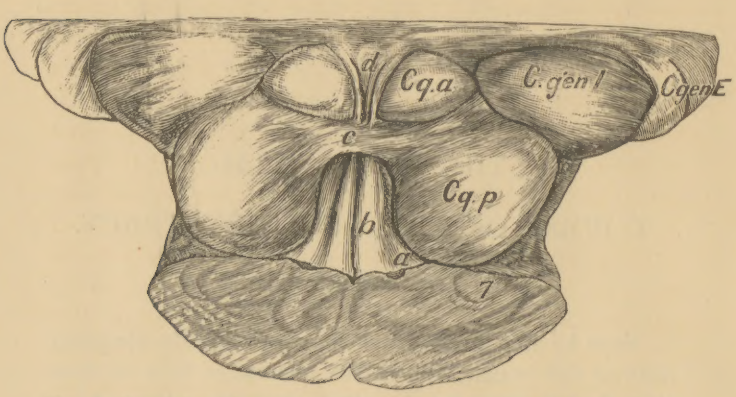

FIG. 1.—Dorsal face of mesencephalic segment of the brain-isthmus of *Tursiops tursio*, a dolphin. *Cq.a*, anterior pair of the corpora quadrigemina; *Cq.p*, posterior pair of same; *C.gen I*, right internal geniculate body; *C.gen E*, right external geniculate body; *a*, peculiar elevation corresponding to tract 6 of Fig. 2.

One of the most instructive cases is that of the porpoise and dolphin; indeed, the *Cetacea* generally. Years ago I directed attention to this fact.* The whales, dolphins, and porpoises have no functional hind limbs; in addition they have, relatively speaking, the largest auditory nerves in the animal kingdom. I was in a position to show that they have no pyramid tract,† and, by a number of comparisons with other species, derived the conclusion that this tract keeps pace in the animal kingdom with the extent to which intelligent and skillful control of the digits and the distal segments of the extremities is developed.

* "Chicago Medical Review," 1880; "American Journal of Neurology and Psychiatry," 1883, vol. ii, No. 4; "New York Medical Journal," September, 1881; "Alienist and Neurologist," July, 1885.

† This fact is referred to in several of the above publications, but not described in detail until the early part of this year in "The Comparative Anatomy of the Pyramid Tract." "Journal of Comparative Medicine and Surgery," January, 1886.

The brain-isthmus, the great general conduit through which the tracts of various function are conveyed to the brain proper, is very much simplified in its anatomy by the absence of the pyramid tract, and the atrophied state of the posterior columns of the spinal cord.* This involves a corresponding reduction of their cephalic prolongations. It is this very simplification which throws into enormous relief certain other tracts and ganglia, which are found in corresponding development in no other animal, nor even in man. Among these are the nuclei, roots, and tracts connected with the auditory nerve. The trunk of this nerve is larger than one half of the lumbar spinal cord; both nerves together nearly equal the trans-section area of the spinal cord at its upper portion.† We are consequently able to study the influence of auditory hypertrophy on brain architecture in the cetacean group of animals better than in the seals.

On looking at the dorsal aspect of the brain-isthmus, we are struck by the enormous preponderance of the posterior corpora bigemina. Instead of corresponding to the anterior pair, as they do very nearly in all land animals who possess functional eyes, they represent four times as great an area in projection. In cubic dimensions this preponderance is vastly greater. The internal corpora geniculata, which keep step with the posterior pair in the animal scale, are correspondingly prominent, occupying nearly the entire area of the posterior face of the thalamic region (Fig. 2). In some species (individuals ?) they are flat, in others they

* "New York Medical Journal," September, 1881: "In the porpoise the posterior columns are in a natural atrophy, though the muscular sense of this animal must be exquisite." Guldberg ("Christiania Videnskabs-Selskabs Forhandlinger," 1885, No. 4) confirms this statement as to the atrophy of the posterior segment of the trans-section of the cord.

† "Notes on the Anatomy of the Dolphin's Brain," "Journal of Comparative Medicine and Surgery," April, 1886. Both auditory nerves measure one hundred millimetres in square area, while the lumbar cord measures but eighty-five millimetres.

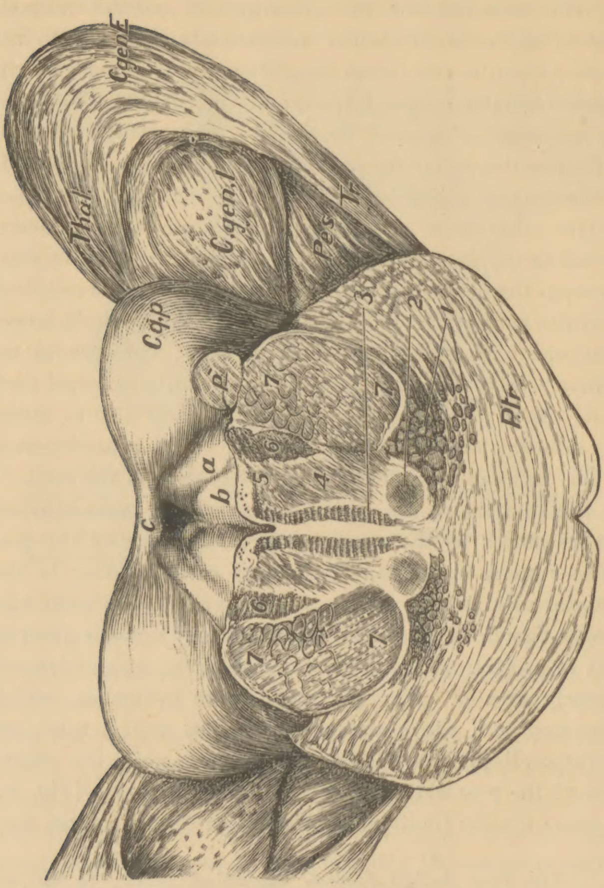

FIG. 2.—Posterior face of mesencephalon and thalamic region of *Tursiops tursio*. The details of the surface, exposed by cutting the posterior part of the pons away from the mesencephalic portion, are indicated by numerals and *Ptr*; the transverse pons fibers. This is the posterior aspect of the segment the dorsal face of which is shown in Fig. 1; *C.gen E* and *C.gen I*, the external and internal geniculate bodies; *Tr*, optic tract; *Cq.p*, posterior pair; *p'*, section of same, where the knife grazed it, showing fusion with 7, 7, the "auditory" division of the lemniscus; 6, *processus e cerebelli ad cerebrum*; 2, a tract corresponding in position to the "fascicle" from the pes to the tegmentum of Henle; 1, the beginning formation of the *pes* which is represented in the *Cetacea*.

appear more rounded; but in area they exceed the external corpora geniculata as much as the posterior pair of the corpora quadrigemina exceeds the anterior. This relation is repeated in the seals, only here the discrepancy between the two corpora bigemina is not so great, while the internal geniculate body constitutes a bolder prominence, if not fully as large a one as in the dolphin.

On making a section through the isthmus immediately behind the post-optic lobes, as in the figure, the details of the section appear so atypical that it becomes almost impossible on first sight to identify them. There is no pyramid tract in the pons, and that part of the lemniscus which is most prominent in man—the middle part—appears to be absent. The brachium conjunctivum (*processus e cerebello ad cerebrum*) appears crowded mesad by an enormous tract which corresponds to the lateral part of the human lemniscus. The continuation of the posterior commissure in the mesal division of the reticular field is very prettily seen. Of the inner division of the lemniscus, nothing is seen except the very distinct bundle from the pes to the tegmentum of Henle.

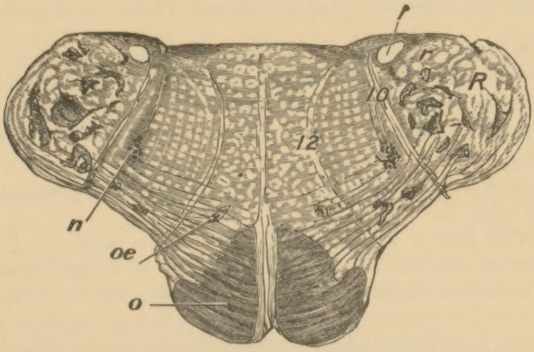

FIG. 3.—Section through middle of olive of *Tursiops tursio* (bottle-nosed dolphin). *o*, olive; *oe*, external olive; *t*, solitary bundle; R, restiform column; *n*, nucleus of laryngeal muscles.

In earlier years, when my series of sections was an imperfect one, I suspected that the great development of

the fasciculus olivarius was related to the hypertrophy of the lateral division of the lemniscus. But, as is shown in Fig. 3, the olivary elevation in the porpoise is entirely ganglionic,* and nothing is more positive and clear than that the olivary nuclei are solely connected with the restiform column in this level. On supplying the gap in my series, I found the solution of the problem in the auditory nerve-root and the related trapezium. The trapezium is relatively the largest in the animal kingdom. In the cat it is as prominent a feature of the trans-section. But, the entire brain-isthmus being of a higher type in the porpoise, the real preponderance of the trapezium is so much greater in the marine animal. It is so massive that, notwithstanding the antero-posterior extent of the pons, the latter fails to conceal the trapezium entirely.† Its cells are very numerous and far larger than in man or other species. Now, the remarkable fact, plainly visible as in no other animal, is that the trapezium fibers can be seen massing into a longitudinal strand, which, followed up from section to section, is identified with a remarkably voluminous tract which occupies the situation of the lemniscus and passes into the posterior pair of the corpora quadrigemina. There is thus estab-

* To convert the cetacean medulla into the human, the olives would have to be separated by the interolivary layer, and the pyramids appended to this wedge below. These two tracts, representing the muscular sense and voluntary motor innervation of free prehensile extremities, are absent, or nearly so, in an animal which, with a high intelligence, has yet in its external form undergone a retrogression to the fish type.

† In the level of the nucleus of the trapezium (upper olive, which measures on each side one third by one quarter of an inch in section) the dorso-ventral depth of the trapezium exceeds the rest of the tegmentum, and the pons; it is pushed up to within a centimetre of the ventricular floor. The rhaphe exhibits a sort of reduplication of the fir-stem which it forms at the trapezial decussation between it and the dorsal part. The "secondary trapezium" thus formed is connected with a special group of cells mesad of the superior olive, and shaped like the scattered cell column found parallel to the ventral part of the raphe.

lished a direct connection between the trapezium and the post-optic lobes through a part of the lemniscus. This, as I have shown in an experiment produced by the atrophy method, is not affected by removal of the cerebrum and thalamus even, or of the anterior pair of the corpora quadrigemina. It is the only part of the lemniscus which is not atrophied on the side where the cerebrum is destroyed.

Baginsky,* in part confirming the results of v. Monakow † and Onufrowicz,‡ found that, on extirpating the posterior or cochlear division of the auditory nerves, the same side of the trapezium, with its nucleus,# the *opposite lower lemniscus*, the opposite posterior tubercle of the corpora quadrigemina, and the opposite corpus geniculatum, underwent atrophy. Now, the case of the *Cetacea* supplements this observation, showing that while atrophy of the posterior division of the auditory nerve produces atrophy of these parts, hypertrophy of the former is associated with hypertrophy of the trapezium, the lateral (lower) part of the lemniscus, the posterior tubercles of the corpora quadrigemina, and the internal geniculate bodies. A clearer proof of the relations of all these parts to the function of hearing sound could not well be expected. But further evidence was furnished by Monakow, who followed up the thread of auditory transmission in that part of its course which is not covered by the experiments of Baginsky or the observations here offered. He found that destruction of the auditory field in the cerebral cortex (Hörsphäre) is followed by degeneration of the internal geniculate body. The course of sound, from its reception in the cochlea to the cortex of that intellectual center, the cerebral hemisphere, is as follows:

* Virchow's "Archiv," 1886, July 3d, vol. cv, p. 28.

† "Archiv für Psychiatrie," xii and xiv.

‡ *Ibidem*, xvi.

Nucleus of the trapezium I proposed terming it seven years ago; it still passes under the misleading name of the "superior olive" in most anatomical writings.

<table>
<tr><td>1. Cochlea</td><td></td><td rowspan="6">Atrophy observation: Baginsky.</td></tr>
<tr><td>2. Posterior division of eighth pair</td><td rowspan="5">Hypertrophy observation: Spitzka.</td></tr>
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<tr><td>7. Corona radiata</td><td colspan="2" rowspan="2">Atrophy observation by von Monakow; experimental observation of Munk.</td></tr>
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The nucleus of nerve-cells in the lower or lateral lemniscus is an enormous one in the *Cetacea*, and alone exceeds the area of the brachium conjunctivum (*Bindearm*). The cells are as large as those of certain motor nuclei.

This observation of the isolated hypertrophy of the auditory tracts and centers is in harmony with the fact that the cetacea possess a remarkably fine sense of hearing, as I have detailed elsewhere. The related hypertrophy of the inner geniculate body in the seal is equally associated with excellent auditory perception. The case of the latter animal, owing to its greater analogy of convolutional type to the dog and other carnivora on which experiments have mapped out the cortical field of hearing, permits us to assert the same hypertrophy of the cortical field of hearing as is found in the lower centers of both seal and dolphin. The cortical field is here so great that the horizontal ramus of the Sylvian fissure is actually crowded into a transverse direction by the former's exuberant development.

In addition to obligations to Professor True, of the Smithsonian Institution, whose admirable catalogue enabled me to identify the species I secured for this study, I must express my gratitude to Mr. Eugene Blackford, Commissioner of Fisheries, for aid kindly extended in obtaining the requisite material. This consisted of three species of our American *Cetacea*, besides two older and imperfect specimens derived from the New York Aquarium many years ago.